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Interim Progress Report #1
Development & Demonstration
of
Nozzles Using Bulk Pyrolytic Graphite

July 1, 1964 - September 30, 1964

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PYROGENICS, INC.
Woodside, N.Y.

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**PYROGENICS, INC.** 25-26 50th STREET • WOODSIDE, NEW YORK 11377

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## Summary

This report is a summary of the first three months of effort on the development of nozzles using bulk pyrolytic graphite. The first 1.120 inch nozzle has been designed and component parts will be fabricated during the next period. The first unit utilizes a plane oriented insulating pyroid insert and was selected in conjunction with Atlantic Research Corporation from four variations of this approach. Preliminary heat transfer,temperature profile, stress and erosion calculations have been performed for the initial design and these calculations will be used in conjunction with test firing results to design the larger 2.3 inch demonstration nozzles.

Design of the second development nozzle has been initiated and is partially completed . This unit utilizes partial edge oriented approach to compare performance with the plain oriented unit.

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## INTRODUCTION

This is the first quarterly report for Contract No. AF04(611)-9903 concerning the development and demonstration of bulk pyrolytic graphite for rocket nozzle application. The purpose of this contract is to design, develop and test fire under severe solid propellant conditions bulk pyrolytic nozzles to demonstrate their utility and to take full advantage of the unique physical properties of this material. In designing the bulk pyro nozzles, consideration is to be given to four factors in the following order of importance:

1. Weight
2. Performance
3. Simplicity
4. Size

Four development nozzles will be made utilizing three different orientations. These units have a throat diameter of 1.120" and will be fired for sixty (60) seconds at a Pc of 700 psia and a $T_c$ of 6500°F.

The first of these units has been designed and is being fabricated. The second unit is presently in the design phase and

two others will follow. Based on test firing results on these nozzles two demonstration units having 2.3" diameter throats will be designed and fabricated. The firing conditions will be the same except that the burning time will be increased from sixty seconds to one hundred seconds.

## DESIGN OF THE FIRST UNIT

The general orientation of the first development nozzle was chosen to be the "plane" approach. This means that the a-b plane or layer planes of the pyrolytic graphite follow the inner contour of the nozzle. This orientation achieves the maximum insulation value of the pyrolytic graphite. Four designs utilizing this orientation were prepared in accordance with the overall dimensions of the 1.12 inch test nozzle. The first two units emplcy the pyrolytic graphite as an insert with expansion washers and graphite heat sinks fore and aft and are backed by vitreous silica phenolic for insulation behind the commercial graphite. The only difference Between unit one and two is in the length of the insert and in the method used in retaining it. The other two designs utilize a full Pyroid nozzle for maximum heat distribution over the inner surface as well as full insulation value in the radial direction. Such a design would minimize weight in a tactical unit.

Study of the four initial plane oriented units designed resulted in selection of an insert type rather than a complete Pyroid nozzle to permit a better comparison with other insert materials and to minimize longitudinal stresses in the initial firing. The longer insert of the two insert types was selected to assure a low erosion

rate at the throat entrance and exit section interfaces. The first unit selected is shown in an assembly drawing in Figure 1. Exit and entrance sections are HLM-85 graphite and backing materials are silica phenolics. Copper spacers are used to accommodate expansion of the insert during the firing. These were to be tapered but heat transfer calculations indicate that the temperature differential will only be 3000°F so straight 0.050 inch washers are specified. To accommodate the Pyroid insert and retain it should failure of the HLM-85 exit cone occur, a ramp has been designed on the insert. This ramp presses against the backup HLM-85 which is in turn held by the phenolic and then the steel case. Originally carbon had been specified for the backup material, but the temperature stability of carbon above 3000°F is questionable, so graphite is being used.

## THEORETICAL ANALYSIS

A brief thermal analysis of the nozzle shown in Figure 1 has been made using a simple one dimensional model. The temperature profiles after sixty seconds predicted by these calculations are shown in Figure 2. Note the rather high temperature indicated behind the Pyroid insert. This temperature of 3400°F is not a result of radial heat flow through the pyrolytic graphite insert. The results of radial heat flow calculations are shown in Table I.

| Radial Distance | Temperature* |
|---|---|
| 0.750" | 100°F |
| 0.525 | 100°F |
| 0.300 | 228°F |
| 0.075 | 4000°F |
| 0.015 | 5850°F |
| 0.00 | 6450°F |

* at time t = 60 secs.

However, heat flow from the graphite entrance and exit section essentially short circuit the insert and dump heat into the lower layers. This is shown graphically in Figure 3. Since these calculations are one dimensional and thus grossly oversimplified, verification of this effect must await the results of thermocouple readings during the firing. Prior firings with pyrolytic graphite inserts indicate that large temperature differentials will occur if the insert is thermally isolated. In this unit heat is being distributed more uniformly through the insert to reduce possible thermal stresses in the first layers (i.e. those layers forming the inner contour of the throat) since these have been susceptible to cracking in prior firings of this orientation. Thermocouple locations for the first unit are shown in Figure 4.

A brief stress analysis was performed to determine extrusion forces on the insert in the event that the exit cone fails. The 30° ramp angle was selected to provide a maximum safety factor against insert extrusion and results in a maximum radial deflection of 0.0027 inches under calculated net axial extrusion forces. Stresses in the other components of the nozzle are all well below allowable limits. In some cases undercutting of parts is specified to allow for thermal expansion.

Finally, the thermal expansion of the insert has been calculated and is found to be less than 0.100 inches at temperatures exceeding 3300°F. Straight expansion washers 0.050 inches thick have thus been specified for the two insert interfaces.

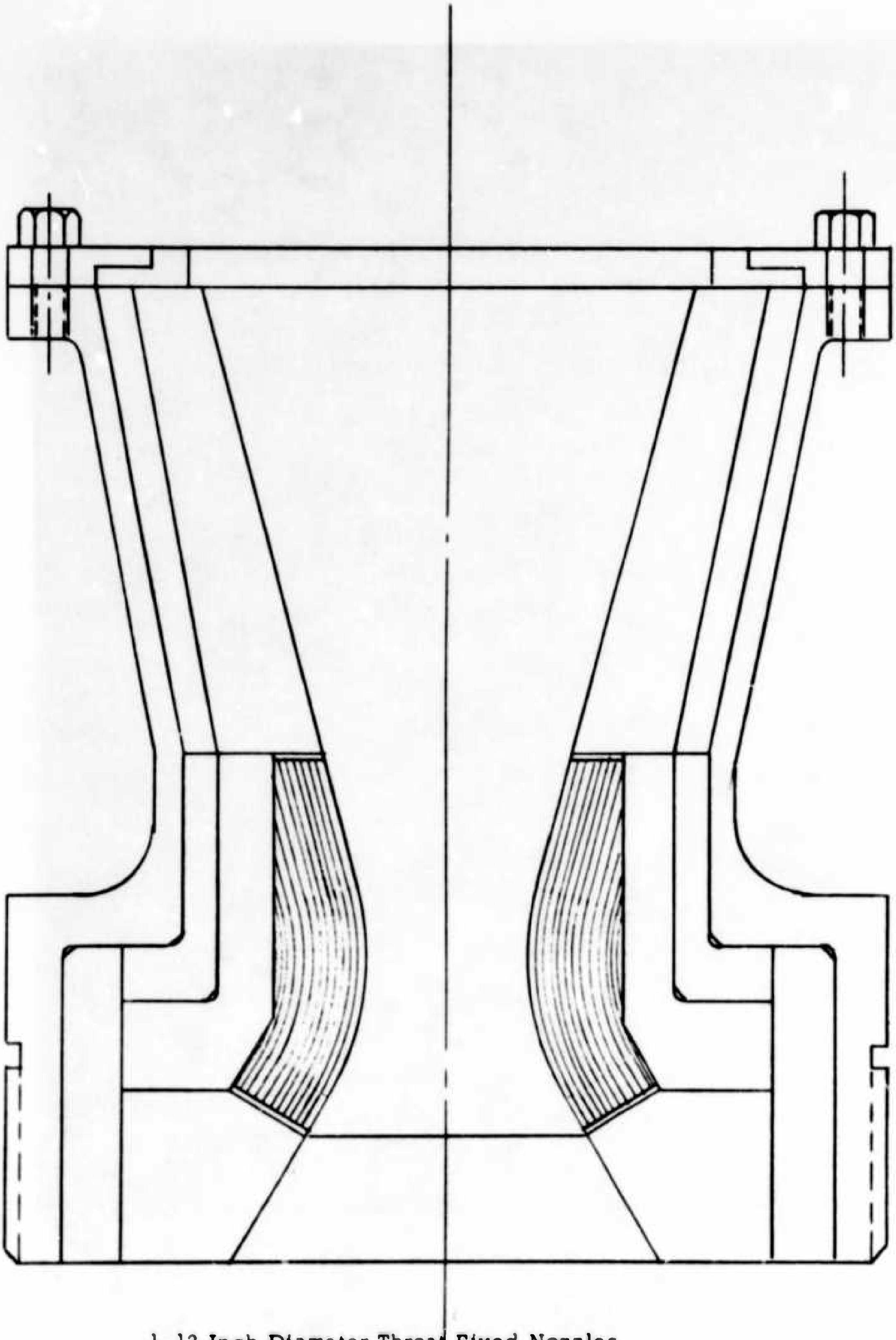
## DESIGN OF THE SECOND UNIT

The second development nozzle is edge oriented in the throat and partial edge in the exit portion of the throat insert. The reasoning behind this design is as follows: Edge oriented pyrolytic graphite is relatively stress free and is quite erosion resistant provided the temperature at the surface stays below temperatures of approximately 4000°F. In heat sink approaches the erosion of the edge oriented washers remains low until thermal saturation occurs. The erosion is then considerably higher than it would be, for instance, for a plane oriented unit at the same surface temperature. It would thus appear advantageous to develop the plane unit with a maximum erosion rate of ~ 0.4 mils/second with high energy metallized solid propellants. However, the thermal or mechanical shock problem to the inner layer has not been adequately resolved so the hybrid unit has been evolved as a possible design compromise.

Specifically then, the second unit utilizes edge grain Pyroid blended into partial edge in such a manner as to conduct heat from the throat and dissipate it in the exit section where a larger area ratio exists. This is shown schematically in Figure 5. Heat transfer calculations should indicate the advantage gained in this design where firing times exceed the heat sink capabilities of the so called washer concept.

## FUTURE WORK

Temperature profiles in the No. 2 unit will be estimated. The third orientation will be selected, if possible, after firing of unit 1 and 2. However, if the schedule does not permit consecutive design, the number 3 unit will be partial edge orientation but with a different heat flow distribution. The fourth unit will then be patterned after the most successful of the first three.



1.12 Inch Diameter Throat Fixed Nozzles

FIGURE 1

## TEMPERATURE PROFILE

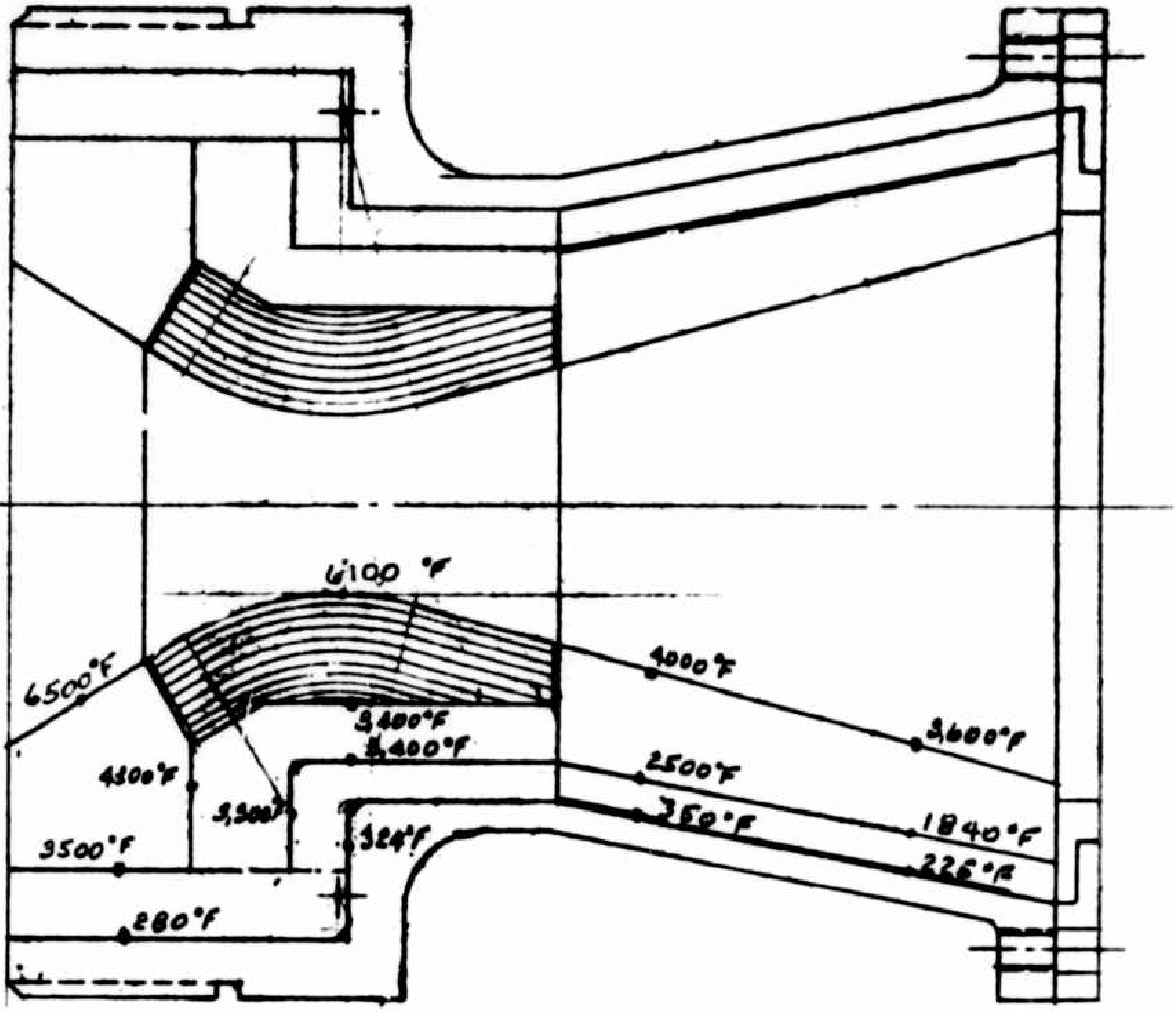
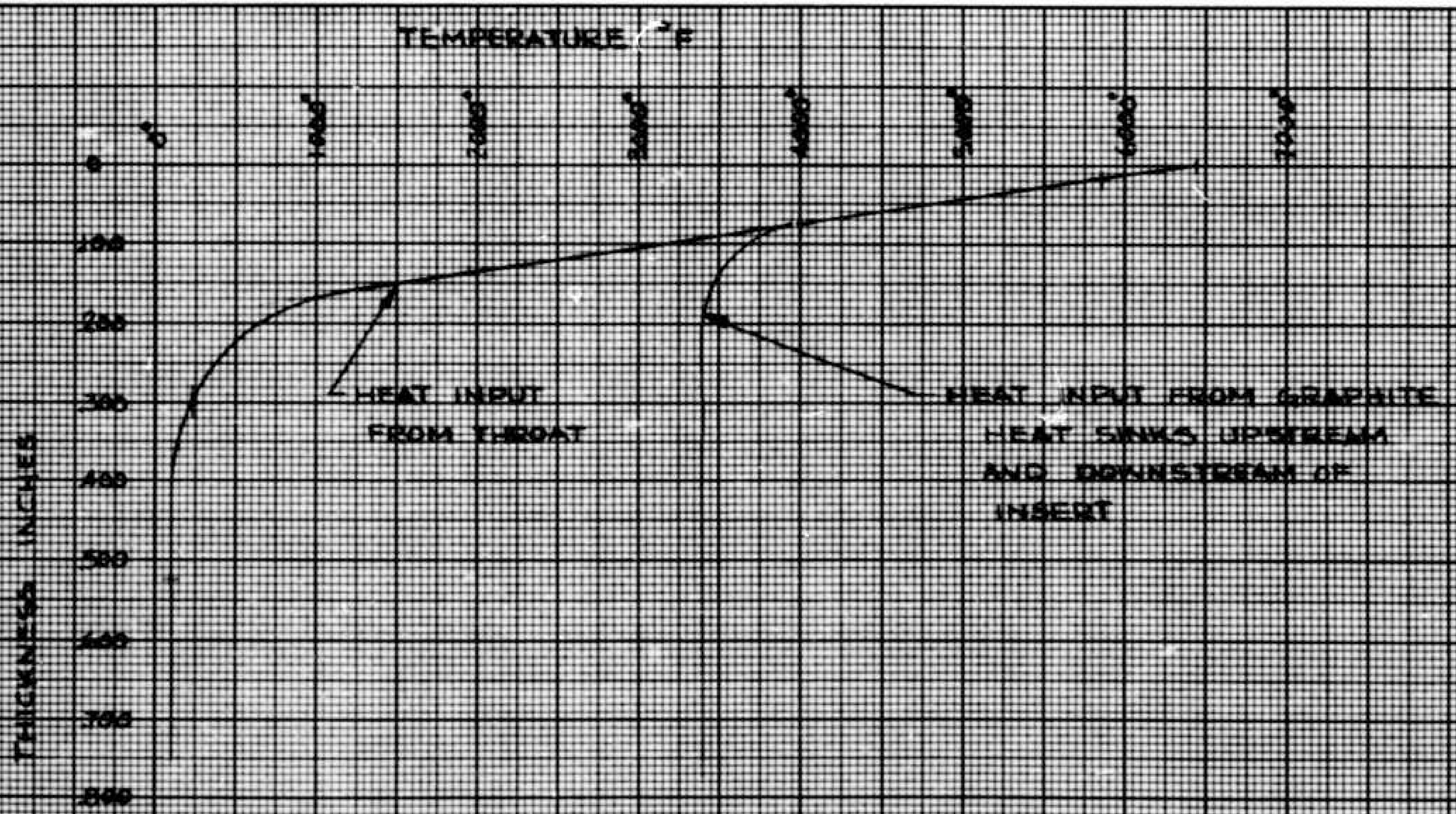



FIGURE 2

TEMPERATURE PROFILE




TEMPERATURE PROFILE ACROSS NOZZLE INSERT
IN THROAT
Figure 3

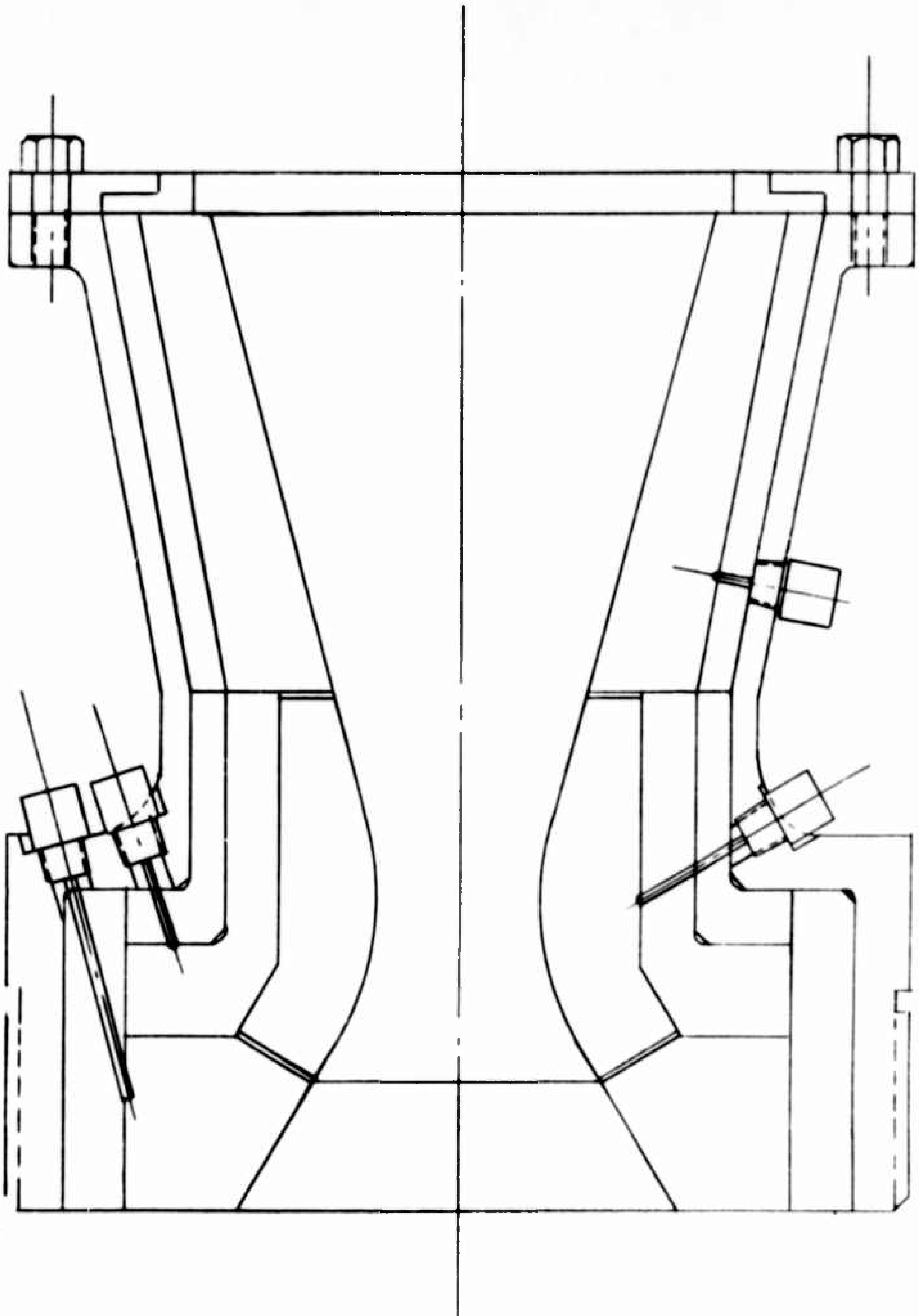
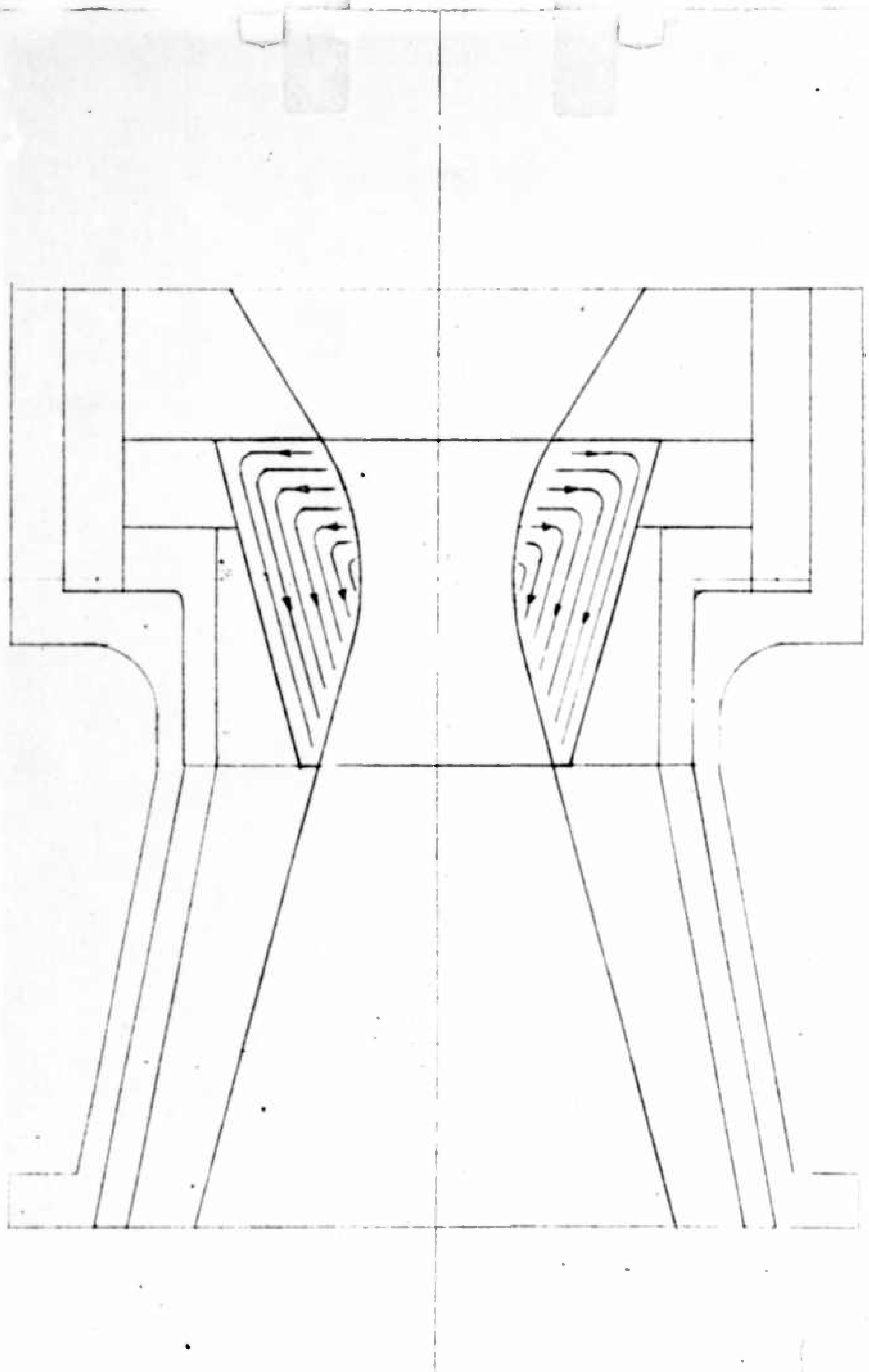


FIGURE 4
INSTRUMENTATION LOCATION



PROPOSED DESIGN OF SECOND NOZZLE

FIGURE 5